DESIGN OF A POWER PLANT FOR AN INTERURBAN RAILWAY

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DESIGN

OF A

POWER PLANT

FOR AN

INTERURBAN RAILWAY

CAPACITY 16000 K. V. A.

A THESIS

PRESENTED BY

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INTRODUCTION.

In designing this 12000 K.V.A. Steam Electric Generating Station for an Interurban Railway, the authors have not attempted to design any particular machine or device, but have undertaken to provide, by selection from various makes on the market, an assemblage of machines and devices, each designed to perform its particular function in the most economical manner and to combine them so as to create one complete unit for the purpose of generating electrical energy from coal on a commercially satisfactory basis.

The authors were somewhat handicapped in not knowing the exact location of the plant, but they selected the apparatus, so that it will be possible to construct it in most any locality.

STEAM POWER PLANT DESIGN

DETERMINING THE TOTAL GENERATING CAPACITY OF THE STATION.

In determining the total generating capacity of the station, several things must be considered; first, the existing load, which is taken from the load curve; second, the possible growth and progress of the supplied locality, since the amount of power required at any time varies with the population. If the power receiving district is so situated, as to become a manufacturing center, this should be considered, since electrical energy is superseding steam in factories and for railway purposes, on account of its flexibility.

The load curve is shown on an accompanying blue-print. The maximum load as indicated by the load curve was 12000 K.V.A. but we have deemed it advisable to make the rated capacity 16000 K.V.A. so as to allow for emergency, in case of an increase of load or a break-down.

SELECTION OF SITE

In selecting a site the engineer is confronted with several problems; first, facilities for freight handling, coal delivery, and removal of cinders. The plant should be located near a railway, which can transport sufficient fuel at justifiable rates, or near a ship canal or river with ample docking space for coal carrying vessels.

There must be available ground adjacent to the station to permit the storage of coal for tiding over a certain period in case of strikes at the mines or on the railroads. The storing space should be so situated as to require a minimum of conveying and coal handling apparatus. Second, an unlimited supply of suitable condensing water must be provided, the temperature of which will not be excessive during the summer time. The water should be free from sewage and other foreign materials, and the location for the station should be such that the intake and discharge tunnels be as short as possible and the lift to the condenser as small as possible. Third, a satisfactory location with a low valuation must be found, which is reasonably at the center of the load. The land acquired should be of sufficient area to provide for future expansion and against the crowding of the power plant equipment. In selecting the site the character of the soil must be well considered with reference to its bearing capacity, to avoid expensive pile driving and large foundation expense.

GENERAL LAYOUT OF STATION.

The superstructure of the plant is of skeleton steel constructed to carry the various floors, coal bunkers, etc. It rests on a foundation of reinforced concrete. The walls are of red pressed brick, trimmed with Bedford stone. The building as a whole is divided into five parts:-

(1) Train shed.
(2) Boiler room.
(3) Turbine room.
(4) Transformer rooms.
(5) Offices.

Those sections of the basement which are located below the above rooms, are included with them.

DETAILS OF THE STATION.

The normal full rated load of the plant is 16000 K.V.A. The load factor taken from the load curve is .75. The small boiler outfit consists of sixteen 750 H.P. Babcock-Wilcox watertube (safety) boilers piped to a common steam loop to which are connected the prime movers. The prime movers are four 4000 K.W. General Electric horizontal steam turbines of the Curtis type; they are the drivers of the A.C. generator sets. The steam consumption has been taken, in calculating the capacity of the auxiliaries, as 15 lbs. per K.W. hour. The turbo-sets are mounted on foundations independent of the main floor; these foundations consist of two concrete-steel column-pillars or blocks, one at each end of a unit, connected across the tops by two large bridge girders or I-beams of proper size. These are placed at the sides of the units so that room is afforded for the exhaust steam outlet into the condenser.

The prime movers with their auxiliaries are divided into two plants. Each plant is absolutely independent of the other, excepting that they are connected to a common steam loop. The two equipments are in duplicate. Each one consists of

Two turbo-generator sets.

Two condensers.

Two vacuum pumps for condensers.

Two circulating pumps for condensers.

Three boiler feed pumps.

One feed water heater.

One hot well.

One Oil separator.

Traps, drains, valves as indicated in detail specifications.

These two plants are located, as indicated, at opposite ends of the power house, with a local sub-station installed between them.

The sub-station consists of three rotary converters, three 3-phase transformers of air cooled design, two induction motor-driven centrifugal blowers

and three voltage regulators. Below the main floor under the transformers for the sub-station is a specially constructed air chamber, with a double door ante-room, so as to keep the pressure constant when anyone enters.

The excitation equipment consists of two induction motor-driven exciters of 85 H.P. each, and one steam-driven exciter of 75 H.P.

The main transformer equipment consists of twelve step-up transformers, installed three in a group, each group in a separate compartment on the main floor in rooms that are at the side of the building farthest away from the boiler-room. They are of oil insulated, water cooled design; the oil being cooled by water forced through by city pressure, or small motor-driven pump. A pumping outfit is shown in the drawings, and described under Detail Specifications.

The main switchboard is located on a gallery in the turbine room and above the transformer rooms. The D.C. Switchboard is located on the main floor, directly behind the converters in the turbine room.

The main crane is of 60 tons capacity, and is located up in the top of the turbine room. A smaller one is also provided for use in unloading coal.

The coal is fed by an automatic chain grate system in pulverized form. A crusher is located in the boiler room basement to take care of the lump coal. The coal is carried to the grates, and ashes carried from them by means of a conveyor system. The The boilers are fitted with ash hoppers and fine coal hoppers. The main coal hoppers are of special design to conform to the spacing of columns and roof girders and the setting of the boilers. Two smoke stacks are used. They are located at the center of the boiler room. About half way between the stacks and each end of the boiler room is an open air exhaust; these being constructed of sheet steel or piping.

The supply water main runs along the length of the building, but its position below the basement floor and distance from walls may be altered and provided for, as referred to under <u>Optional Construction</u>. The waste main runs parallel to the feed main and can also be shifted if necessary.

Piping:-

The main header was calculated from a formula given in Gebhardt's Power Plant text-book. The auxiliaries are all piped to the main header, as indicated. The circulating pump and the condenser pump for each turbine has a separative live steam supply pipe of its own connected to

the local header, but the exhaust of the two sets of auxiliaries is brought to a common header and connected to the exhaust of the feed pumps. The feed pumps have their own live supply pipe. The condensation from each pair of condensers is piped to a common hot well. The two hot wells are connected by a pipe so that either set of feed pumps can draw water from the other hot well.

Two lines of feed water supply pipe are provided for. In case of breakdown of one, the other can be used, or each set of pumps can use one line.

The apparatus already described is chiefly what may be termed regular apparatus. For special purposes several pieces of machinery have been added. They may be called special apparatus, and will be described as fully as possible under Detail Specifications.

A special outfit for the handling of transformer oil is to be installed and operated in conjunction with the water circulating system by means of which the main transformers are kept cool. This oil handling system was designed according to the ideas of Mr. *Fred Buch* of the transformer department of the G.E. Co., and differs only in minor details; pipe dimensions, etc., from the outfit described by him in the *Electrical World* for *Dec, 7, 1912* .

An air compressor will be provided to furnish compressed air for cleaning rheostats, armatures, and for miscel-

laneous purposes.

Two high pressure auxiliary pumps will be installed, to be used for fire protection purposes, or to supply water for irregular use about the station.

The lighting of this building, as provided for under the present arrangement, is taken care of by the local converters. They will be used in conjunction with a set of storage cells.

A small repair shop will be included within the plant, and part of the boiler-room basement will be portioned off into store rooms.

CALCULATION OF AUXILIARIES.

The size, type and capacity of some of the auxiliary machinery has been obtained directly by reference to the various catalogs of the makers, but several items have been calculated. They are:

Main Header.
Condenser.
Boiler Feed Pumps.
Main Centrifugal Pump.
Engine for same.
Sirocco Fan Motor.
Transformer Circulating Pump.

These pieces of machinery have been calculated chiefly by methods and formulas given in Gebhardt's work: Steam Power Plant Engineering.

Calculation of the Main Header.

Under the assumption that the turbines use 15 lb. of steam per K.W. hour,

15 x 4000 = 60,000 lb. per hr. per unit.

= 240,000 lb. per hr. for the four units.

= 4,000 lb. per minute for four units.

allowing 1/2 extra for overloading, brings it up to 6,000. Take the weight per cu. ft. as .5 lb.

Then $d = .175 \left(\frac{6000}{.5}\right)^{\frac{1}{2}}$

$= .175 \times 12{,}000^{1/2}$ $= .175 \times$ antilog of $\frac{4.0792}{2}$

= .175×antilog of 2.0396 which is 108.1 = 19 inches. therefore the diameter of the main header will be made from 15 to 20 inches, 18 being a good value.

Calculation of the Condenser

Vacuum assumed = 27 inches of mercury which is equivalent to 3 inches of pressure.

15 lb. of steam per K.W. hour as before.

x = .9   1 inch of mercury is equivalent to .4912 of a lb. per sq. in.   3x .4912 = 1.4736 = 1.47, nearly 1 1/2 lb.

From the steam table the total heat at this pressure is 1109.7 per lb. 1109.7 x .9 = 998.73- call it 999 $= \lambda$

Temperature of cooling water assumed 80°

$$T_s = \frac{(101.83 + 126.15)}{2} = 113.99, \text{ call it } 114.$$

$$T_o = 80 \qquad T_1 = T_s - 4 = 110 \qquad T_2 = T_s - 5 = 109 \qquad d = \frac{T_2 - T_o}{\log e \dfrac{T_s - T_o}{T_s - T_2}}$$

$$d = \frac{109 - 80}{\log e \dfrac{114-80}{114-109}} = \frac{29}{\text{Log } e\ 6.8} = \frac{29}{\log 10\ 6.8 \times 2.303}$$

$$= \frac{29}{2.303 \times .8325} = \frac{29}{1.917} \quad 15.2 \qquad S = \frac{w(\quad - T_1 + 32)}{600 \times d}$$

$$\text{Then } S = \frac{15(999 - 110 + 32)}{600 \times 15.2} = \frac{15 \times 921}{600 \times 15.2} = 1.52$$

∴ the turbine will require 1.52 sq. ft. of condenser surface per K.W. Therefore 4000 x 1.5 = 6000 = total surface in sq. ft. of the condenser for each turbine. Allowing extra surface for overloading, warm circulating water, or other unfavorable conditions, we have selected the condenser of 7500 sq. ft. already referred to.

Calculation of the Boiler Feed Pump.

Estimation of gallons per hour.

Each group of eight boilers must supply steam for two 4000 K.W. units and their auxiliaries.

Since 15 lb. of steam is used per K.W. hour, 15 lb. of water must be evaporated per K.W. hour;(as a matter of fact, a little more, since the 15 lb. takes into account the steam consumption of the main turbines only).

8,000 x 15 = 120,000 lb. of steam (or water) which must be supplied by two pumps, = 60,000 lb. per hour per pump. This must be changed to gallons per hour in order that we may select the proper size of pump from the maker's catalog. 3 gallons weigh roughly 25 lb. $60{,}000 \times \frac{3}{25} = 7{,}200$ gallons per hour per pump, say 7,500. From these figures the pump was chosen.

Calculation of the Condenser Circulating Pump.

Substituting values in the formula $W = \frac{- T_1 + 32}{T_2 - T_0}$,

in which $\lambda = 999$

$T_1 = 110$ it becomes $\frac{999-110+32}{109-80} = 29\ 1/2$

$T_2 = 109$

$T_o = 80$

This means that 29 1/2 lb. of cooling water will be required to condense each lb. of steam.

60,000 lb. will require 60,000 x 29.5 = 1,770,000

$1,770,000 \times \frac{3}{25} =$ 212,400 gallons per hour for each condenser, say 220,000.

Calculation of the engine for the Circulating Pump.

1,770,000 lb. per hour is 29,500 lb. per minute; call this 33,000 lb. per minute. The height or head through which it is lifted is 18 ft.

Then 33,000 lb. raised 18 ft. per minute will require 18 H.P. At the most a 20 HP engine should be large enough.

Calculation of the Sirocco Fan Motor.

According to Hobart, the power necessary to drive blowers for air cooled transformers may be taken as 1% of the total K.W. capacity of the transformers to be cooled.

In this case the total K.W. is 3000.

3,000 x .01 = 30 K.W. = 30,000 watts. 1 H.P. = 746 watts say 750. Then $\frac{30,000}{750} = 40$, 40 H.P.

This is the power of the two motors, as a maximum value. A lower value, from 5 to 10 H.P. per motor, has been assumed.

Calculation of motor and pump for main Transformer Cooling Outfit.

From data given in Hobart's book on transformers, we

estimate that the main transformers will require 600 lb. of water per hour per 1000 K.W. For six 1000 K.W. transformers the quantity per hour is 3600, or 60 lb. per minute. $60 \times \frac{25}{3} = 500$ gallons per minute. This is a rough estimate of the capacity of the pump. Taking the height from cold main to transformers as 50 ft., then $40 \times 60 = 2400$ ft.lb. per minute $= \frac{2400}{3300}$ of a horse power. Apparently a motor of 1 H.P. would do the work, but a larger one has been taken.

DETAIL SPECIFICATIONS.

Details of Turbo-Generator Sets.

Turbines - Curtis Type; 180 lbs. steam pressure.

Generators - Type M., A.T.B. 6 pole, 4000 K.V.A., normal full load capacity. 2300 volts. 1200 R.P.M.

Maker- General Electric Co.

Details of Condensers.

The condensing outfit chosen is known as the Wheeler high vacuum condenser. There is only one vacuum pump used. The condensing tank is made to order and fitted with a special design of exhaust steam chest to the exhaust outlet of the turbine as indicated. The capacity of the condenser has been calculated to be 7500 sq.ft. for each unit, but it may be desirable for the exhaust of the auxiliaries to be handled, together with the exhaust from the main turbine; so that a larger size tank, or pump, or both, may be necessary.

Details of Circulating Pumps.

No allowance has been made for water pressure in the supply main, the assumption being that the pump must handle water from zero pressure. The pumps are the Worthington make of the Volute Centrifugal type, steam engine driven. The H.P. of each engine is approximately 20, but both pump and engine will be chosen of a size sufficiently large to

take care of any over load that the turbo-generator can handle, and to work smoothly with the other auxiliaries. The make of the engine is not definitely known; it is supplied by the Worthington Co. and will be whatever they may send out. It is a vertical, simple, single cylinder type, direct connected to the pump.

The pump must lift water thru a height of 18 ft., and each one must supply to its condenser about 220,000 gallons per hour. This type of pump can handle water up to 85 ft. with 85% efficiency. For further details see the maker's catalog.

Details of Boiler Feed Pumps.

The boiler feed pumps are of Marsh make, simplex type. At a steam pressure of 80 lbs. the capacity if 6000 gallons per hour, with water pressure of 180 lb. per sq. in. The steam cylinder is 12" x 12" and the water cylinder is 5" x 12". Listed as type S, Krixm in the catalog.

Details of Feed Water Heater.

Two heaters are provided, one for each pair of turbines. They are of Webster make, open type, 7500 H.P. boiler capacity each, designated as type ED in the catalog.

Details of Hot Well.

There are two hot wells, one for each pair of turbines and feed water heater. They consist of steel tanks sunk below the basement floor. Size 16'x8'.

Details of Oil Separator.

There are two separators for each pair of turbines. One of them is located in, and is a part of, the feed water heater. The other is located between the auxiliary exhaust line and the condenser tanks. It is of Webster make, vertical type.

Details of Sub-Station.

Converters.

There are three converters of same type and equal capacity. Capacity 1000 K.W. [illegible] volts on the D.C. side. Frequency, 25 cycles.

Transformers:-

The transformers are air cooled, with a capacity of 1000 K.W. each. General Electric Company's make.

Blowers:-

Blowers are of the Sirocco make. Type A. Motor-driven, under pressure of 3 oz. to the sq. in. 12,000 cu.ft. air per minute. H.P. of the Induction motors used to drive them is not definitely known, but roughly, each one will be of 5 H.P. and 10 as a maximum.

Details of Exciters.

There are two induction motor-driven exciters, connected to high speed D.C.generators. The motors are 90 H.P., and the generators are of 85 K.W. each. There is

also one steam-driven exciter, the turbine of which is 75 H.P., and the generator is of 60 K.W. The exciters are of G.E. or Westinghouse make.

Main transformer details.

Make: General Electric Co., oil insulated, water cooled, step-up, 2300 to 66000 volts. The cooling is accomplished by a water circulating system, operated by two induction-motor-driven centrifugal pumps of suitable size. Each one pumps cooling water through six of the twelve transformers.

The H.P. of the induction motors and the capacity of the pumps is not definitely known, but this is a comparatively unimportant detail. As a rough estimate, however, based on data given in Hobart's book on transformers, we may say that the H.P. of the induction motor for each pump is about 2, possibly 3, and not over 5. Each pump must have a capacity of about 600 gallons per hour. The pumps will probably be of Worthington make, and the motors, G.E.

As already mentioned, an outfit for the handling of transformer oil is to be installed. It comprises the following: One large storage tank, located in one of the two store rooms at the train-shed end of the building. One small tank for temporary storage of oil while

cleaning it. One oil trap, used to keep oil out of the air compressor tank, and a treating press, by means of which spoiled oil can be cleaned and made fit for further use. All of these items are located in the basement, and the last three are between the two blowers, as shown.

The air compressor referred to, is located in the basement, in the middle of the building, next to the boiler room wall. Its tank is mounted directly above it, against the ceiling. No details of the compressor are available, but it will be steam driven and of the standard make known as the Ingersoll-Rand.

The two fire-pumps will be located near the compressor, one on each side of it. They will be steam driven, single cylinder, simple, vertical type, closely resembling those used on portable fire-engines. They will be of Worthington or Edwards make. They will be piped to four large reservoirs, steel tanks which are supported from the rafters of the third floor of the transformer room, each tank being located above a group of transformers.

The set of storage cells referred to, which are to be used in lighting the plant, will be installed in the basement in the air chamber. The number, size, and type of the cells has not been definitely decided on.

A coal crusher will be placed in the boiler-room-basement, below the R.R. track, to pulverize the large lumps of coal. A crane is to be put in over the train shed, with a grab bucket, so as to handle coal from such cars as do not have side dumping gates.

Details of the crane and the coal crusher are not yet known.

The small machine shop referred to will be in the turbine room basement, directly below the R.R. track. It will be served by both of the cranes, part of the main floor being left open so that machine parts, etc., can be lowered into it.

The store rooms referred to, are on each side of the coal crusher, one of them being directly adjacent to the repair shop.

Main Crane Details.

60 ton crane manufactured by the Shaw Electric Crane Co., Muskegon, Michigan.

Coal, Ash, Water, and Waste Details.

Chain grates - Either B. & W. or Green make. They are actuated by induction-motors, one to each four boilers. (H.P. and details of the motors have not been determined. They are supplied by the company which makes the chain grates).

Bucket conveyor is of Hunt make, one line only being used.

Smoke stack, 12 ft. diam., 200 ft. high, steel or masonry; shown of steel.

Water and waste mains - 4 ft. diam.

Main steam header - 15" diam.

Railroad tracks are standard guage.

Boilers.

Sixteen 750 H.P. Babcock and Wilcox, watertube, safety boilers, in pairs, eight on each side of the boiler room, are installed. They are connected to a common steam loop and every boiler can be disconnected separately from the system. They are equipped with superheaters and each one has a by-pass steam outlet, so arranged that the superheater can be cut out of use entirely, and "wet" steam used instead. This provision is made to take care of any case of failure, or injury to the superheater.

Valves, Traps, Drains, etc.

Any standard make, or several, will be used where needed. They are not shown on the drawings.

DESCRIPTION OF OPERATION OF STEAM APPARATUS.

This plant has been designed so that one half of all the power producing apparatus, turbines and accessories can be installed and run independently of the other half. This holds true up to the main transformers but does not include the local sub-station which happens to be divided into three divisions (three converters, each with its transformer and regulator). Each of the main plants consists, as mentioned, of two turbo-generator sets with their auxiliaries. In ordinary running six out of the seven pumps are in operation. The turbines are exhausting into their condensers, but the auxiliaries are exhausting into the feed water heater, and not into the main condensers. Only two of the three boiler feed pumps are in operation, the third is left idle as a reserve for over-load or breakdown. The two boiler feed pumps are working in series, one of them feeds water from the hot well into the heater, the other feeds from the heater into the eight boilers, or equivalent to half of all the sixteen boilers. The one that feeds from the heater to the boilers is considerably overloaded, because it has to pump the same quantity out of the

heater that the other pumps into it, but against 200 lbs. of boiler pressure besides. The other pump is rather underloaded and it will either be run slower by cutting down its steam supply or will be run at intervals. The last scheme is more economical, especially if the heater has reserve capacity enough to supply the high pressure pump for a while. Type E D heater with extra storage capacity, as listed in the maker's catalog, will be specified. The pump which pumps into the heater has less work to do than the other, because it pumps against a vacuum, or at the most against a pressure only two or three pounds above atmospheric pressure, while the other must pump against a 200 lb. boiler pressure. This pump could be of smaller size than the other, but all three will be of the same size and they can alternate in feeding the boilers. This is more convenient, because any one can be substituted for either of the other two without any regard to its size, providing all three are alike and each large enough to feed the boilers direct under normal load. The piping has been arranged so that this can be done. Any one of the three pumps can draw from three separate sources and deliver to two separate destinations. The sources are the cold water main, hot well and the feed water heater, the places fed to are the feed water heater and the boilers. The

ordinary course of the feed water is from the hot well to the heater and from the heater to the boilers; it is also possible to pump from the cold main to the heater and then to the boilers; also from the hot well direct to the boilers, and from the cold main direct to the boilers. The heater can be fed from the cold water main or the hot well. In case of overloading, when only one of the two plants is run; that is, in case of overloading one end of the power house rather than start up the machinery at the other end, e.g., overload for short period only or not enough to make it worth while to start the other units, then the boiler feed pumps of the other units can be used. If all four turbines have to be overloaded, then the third pump in each set can be run, if the other two cannot handle the water fast enough. It would in this case either help the high pressure pump draw from the heater, or else draw independently from the hot well or the cold main and feed direct to the boilers. This last arrangement is possible because there is a double line of boiler feed pipe instead of one. One of them would be carrying hot well water in this case, and the other water from the heater. But in this case part of the water would be unheated.

The feed water heater is of 7500 H.P. capacity and under ordinary conditions it can take care of all the exhaust steam from the auxiliaries. But if the latter are overloaded, or if not enough cold water is fed into the heater to condense all the steam that enters it, then there will be back pressure on the auxiliaries. This has been taken care of. The exhaust of the three boiler feed pumps is tied to the exhaust of the four engine pumps at front and rear and forms a loop. Before it gets to the heater the oil is extracted from it by means of the separator which is installed in the heater for that purpose. The other side of the loop is connected through a single line of pipe, which connects the two condenser tanks. In this pipe the auxiliary exhaust first runs through a separate oil separator. Then it encounters a valve. A gauge is located anywhere in the exhaust loop so that it is easily visible to anyone at the valve. The idea is to set the valve so that the gauge reads zero, or minimum back pressure. If the heater cannot take care of all the exhaust from the auxiliaries, the main condensers can take the surplus, which may be arranged by adjusting the valve until the gauge reads O.K. In case of cleaning or repairs to the heater, the main condensers can, since the pipes and the valve will be large enough, take care of all the steam from the auxiliaries.

The engineer in charge will have to come around occasionally and watch the back-pressure gauge and readjust the valve if necessary. The extra oil separator is to keep oil out of the condensers and thus out of the hot well. The exhaust loop is connected to the air exhaust by two pipes, one for the four engine pumps, the other for the three feed pumps, and either group can exhaust into the air by itself, independent of the other group. Each of the main turbines can exhaust into the air direct, if so desired; in case of emergency; and although not shown in the drawings, a valve may be placed in the air exhaust main from the turbine, which will make it possible for either turbine to utilize the condensing outfit of the other one, in case its own were out of commission and it was unadvisable to start the other turbine. The steam driven exciter is shown exhausting directly into the air exhaust main, which is satisfactory from an economical standpoint, since it uses very little steam and is run only occasionally. Each main turbine has a valve in its air exhaust branch, which is closed tight when using the condenser, so that the latter can not draw air thru it and spoil its vacuum.

In the operation of the exciters, the steam driven

one will be used only in starting up the plant and in times of overload; the two motor-driven ones being of sufficient capacity for all ordinary loads.

The railroad track in the transformer room is depressed so that the top of the car will be even with the floor. In this way the transformers can be slid into their position without very much difficulty. Two turntables are provided in order that the bend around the corner can be made with ease. Flat cars can come all the way into the turbine room and then the 60 ton crane can handle the apparatus and set it into place.

OPTIONAL LAYOUT AND INSTALLATION

Slight changes may be made in the size and type of machinery in this plant, and in its position in the plant.

750 H.P. boilers have been specified but larger ones may be installed if this is desirable, provided they do not occupy more floor space than the present ones. Sufficient head room has been provided for 1000 H.P. boilers including clearance for all piping.

A blower system to handle the ashes is deemed advisable but it has not been shown. The bucket conveyer handles the ashes at present.

A 7500 H.P. capacity feed water heater has been selected, as mentioned, but there is plenty of room left for a larger one if this is desirable. Instead of being mounted at one side of the three feed pumps on a brick foundation, it may be mounted above them on a steel framework.

The true shape and size of the steam chest under each turbine is not indicated by the one shown in the drawings but plenty of room is provided under the turbine bed plate for a larger one than that shown.

Instead of three feed pumps as already described, we may retain two of them and substitute for the third,

one of the following dimensions: Steam cylinder 12" x 12". Water cylinder 12" x 6". Gallons per hour,8750, at 80 lb. steam pressure. Water pressure 120 lb. Type S, Kropex. This would supply the heater only.

The supply main is shown under one of the turbine foundations. It is preferable to have it on the same level as the discharge main, but in order to have it so, it will have to be moved 10 ft. or more, nearer the main transformers, and this would necessitate longer intake pipes to the pumps.

As arranged at present, the storage cells, used for lighting purposes, are charged by the rotary converters, but instead of doing this, it may be preferable to put in a small converter, for their use alone, or a small induction-motor driven D.C. generator. It would be installed in the basement near the air compressor. Size, details, etc., are not yet fixed on.

The two store rooms near the coal crusher may be used for storage of coal instead of supplies.

TRANSMISSION LINE DESIGN.

1. Power transmitted - - - - - - - - - - - - - - 12000 K.W.
2. Frequency - 25 cycles.
3. Number of phases - - - - - - - - - - - - - - 3
4. Distance - 60 miles
5. Number of wires - - - - - - - - - - - - - - - - 3
6. Voltage at receiver end - - - - - - - - - - - 66000 volts
7. Economic drop - - - - - - - - - - - - - - - - - 5.7%
8. Resistance per wire - - - - - - - - - - - - - 19.4 ohms
9. Kind of wire - - - - - - - - - - - - - - - - - - hard drawn coppe
10. Size of wire - - - - - - - - - - - - - - - - - - #000 H. & S.
11. Distance between wires - - - - - - - - - - - - 80 inches.
12. Inductance per wire - - - - - - - - - - - - - 10655 Henrys
13. Capacity per wire - - - - - - - - - - - - - - 1.02 M.F.
14. Natural frequency - - - - - - - - - - - - - - 760 cycles
15. Charging current - - - - - - - - - - - - - - 6.1 amp.
16. Apparent power at no load - - - - - - - - - 347.5 K.W.
17. Inductive reactance per wire - - - - - - - 16.7 ohms.
18. Capacity reactance per wire - - - - - - - - 6250 ohms.
19. Rise in voltage at no load - - - - - - - - - 51 volts
20. Regulation for full load - - - - - - - - - - 5.13%
21. Minimum allowable distance between wire and ground - 19.5 inch
22. Distance between towers - - - - - - - - - - - 400 ft.
23. Conductor weight per tower - - - - - - - - - 609.6 lbs.
24. Sag at zero degrees - - - - - - - - - - - - - - 7.05 ft.
25. Sag at 100 degrees - - - - - - - - - - - - - - 9.85 ft.

TRANSMISSION LINE DESIGN

CALCULATION

Economic drop:-

$X = -3/4xK/E^2C_1 + 1/4E^2C_1 \times \sqrt{9K^2 + 12E^2C_1K}.$

$K = p_2 c_2 K_1 K_2 4L_1^2 1000.$

p_2 = interest rate on cost line conductors = .09%

c_2 = cost of conductor in dollars per lb. = $00.15

c_1 = cost of energy in dollars per kilowatt-year at generating station - - - - - - - $15.00

k_1 = resistance in ohms per mile of conductor having one circular mil. cross-section,= 54,669

k_2 = weight in pounds per mile of conductor having one circular mil. cross-section - -.916

L_1 = distance in miles - - - - - - - - - - - 60

X = 4x.09x.15x54669x.016x60x1000 = 2,833,920.

$X = -3/4x2,833,920/(66000)^2x16 + 1/4x(66000)^2x\ 15 \times \sqrt{9x(2,833,920)^2 + 12x66000^2x16x2,833,920}.$

X = -.000325 + .0574. = .057.

Economic drop is 5.7% of impressed Voltage.

12000 K.W. is to be delivered.

K.W. to be supplied = $\frac{12000}{(1-.057)}$ = 12700

Size of conductor required:-

$S = 1/2x(1000P/K^2xK_1x2L_1/x).$

= 1/2x(1000x12700/4356x100 x 54669x2c60/.057)

= 167500 circular mils.

= #000 B. & S.

$R = .0617 \times 60 \times 5280/1000$

$= 19.4$ ohms per wire.

Inductance per wire:-

$60(80.5 + 740 \log. 80/.4096)10^{-6}$

$L = .10655$ henrys.

For two conductors $= 2 \times .10655 = .2131$ henrys

Capacity per wire:-

Between neutral plane and either conductor micro-

farads per mile =

$C = .0388/\log_{10} d/R = .0388/2.2912 = .017$ M.F.

Capacity for whole length = 1.02 M.F.

Between two conductors = .51 M.F.

Natural frequency:-

$1/4\pi Lc = 1/4 \sqrt{.2131 \times .00000051}$

$= 760$ cycles.

$I = 2\pi fEC \times 10^{-6}$

$= 2\pi \times 25 \times 66000/\sqrt{3} \times 1.02 \times 10^{-6}$

$= 6.1$ cycles

Apparent power at no load:-

$P = 66000 \times 3.05 \times 3$

$= 347.5$ K.W.

Inductive Reactance per wire:-

$X = 2\pi fL$

$= 2\pi \times 25 \times .10655$

$= 16.7$ ohms

Capacity Reactance:-

$X = 1/2\pi fc$

$X = 10^6/2 \times 25 \times 1.02 = .6250$ ohms.

Rise in voltage at no load:-

$= 2\pi fLIc/2 = 2\pi x25x.1065x6.1/2 = 51$ volts.

Regulation:-

$L = .02131$ henrys.

$C = .051$ M.F.

$R = 1.04$ ohms.

$K = 66000\ (/-.057) = 62238$ volts.

$I = 1,200,000/62238 = 19.2$ amperes.

Resistance drop:

$IR = 19.2x1.94 = 37.25$ volts.

Resistance drop:-

$2\pi fLI = 50x\pi x.02131x19.2 = 64.2$ volts.

$E_1 = (62238 + 37)^2 + (64.2)^2.$

$= 62275.8$ volts.

$I_1 = .(19.2)^2 + (50\times\pi\times 62275\ x.051x10^{-6})^2,$

$= 19.21$ amperes.

$E_2 = 62132.76$ volts.

$I_2 = 19.22$ amperes.

$E_3 = 62350.04$ volts.

$1_3 = 19.23$ amperes.

$E_4 = 62387.34$ volts.

$I_3 = 19.24$ amperes.

$E_3 = 62424.66$ volts.

$I_5 = 19.25$ amperes.

E_6 = 62462 volts.

I_6 = 19.26 amperes.

K_7 = 62499.36 volts.

I_7 = 19.217 amperes.

E_8 = 62536.174 volts.

I_8 = 19.28 amperes.

E_9 = 62574.14 volts.

I_9 = 19.29 amperes.

E_{10} = 62611.56 volts.

I_{10} = 19.30 amperes.

Regulation:-

66000-62611/66000 = 5.13%

Minimum allowable distance between wire and ground:-

$E = gr. \log_e R/r.$

$2x66000 = 100000x.2048x2.303 \log R/.2048.$

R = 19.5 inches.

Distance between towers:-

400 ft.

Weight per tower:-

$3x400x.50^8 = 609.6$ lbs.

Sag of conductor:-

Wind pressure 15 lbs. per sq. ft. of projected area.

Wt. per ft. = .508 lbs.

Area of conductor = .1315 sq.in.

Outside diameter = .4096 of an inch.

Ice coating is assumed 1/2" thick.

Weight of ice-coating alone is:

$$12\pi \frac{(1.4096/2)^2 - (.4096/2)^2}{1728} \times 57 = .572 \text{ lbs. per ft. of cable}$$

Wt. of cable and ice = 1.08 lbs. per ft.

Wind pressure on ice covered cable is

$1.4096 \times 12/12 \times 15 = 1.62$ lbs. per ft.

Resultant of weight and wind

$\sqrt{(1.08)^2 + (1.62)^2} = 1.945$ lbs. per ft.

Wind pressure on cable without ice.

$.4096 \times 12/144 \times 15 = .471$ lbs. per ft.

Resultant of weight and wind pressure.

$\sqrt{\overline{.508}^2 + \overline{.471}^2} = .694$ lbs. per ft.

$S_1 = 400$

$W = 1.08$

$W_r = 1.945$ at 32° F and .694 at 66° F.

$A = .1315$

$T = 60000 \times .1315 = 7890$

$T = 0.75$ and 150

$K = .0000168$

$K_1 = 15000000$

$L_s = S_1 + S_1^3 W_r^2/24T^2$

$= 400 + \overline{400}^3 \times \overline{1.945}^2/24\times\overline{7890}^2$

$= 400.83$

$$L_u = \frac{L_s}{1 + \frac{T}{AE_1}}$$

$L_u = 400.80/1 + 7890/15\times10^6 \times .01315$

$= 400.83$

Higher range temp.:-

400.298 L_s and L_u

Sag:

$$D^3 - 3S_1/8\ (L_u(1+K+) - S_1)\ D = 3S_1^{\ 3}L_uW_r/64AE$$

Temp. -0° and 100°

at 0°

$$D^3 - 3x400/8\ (400.83(-400)D = 3x\overline{400}^3 x400.83/64x15x10^6 x.1315$$

$$x1.945$$

$$D^3 - 94.5D = 1480$$

$$D = 14.3 \text{ ft.}$$

Vertical sag $D' = 1.08/1.945 \times 14.3 = 7.95$ ft.

at 100° F.

$$D^3 - 3x400/8\ (400.998\ (1+.00168) - 400)\ D$$

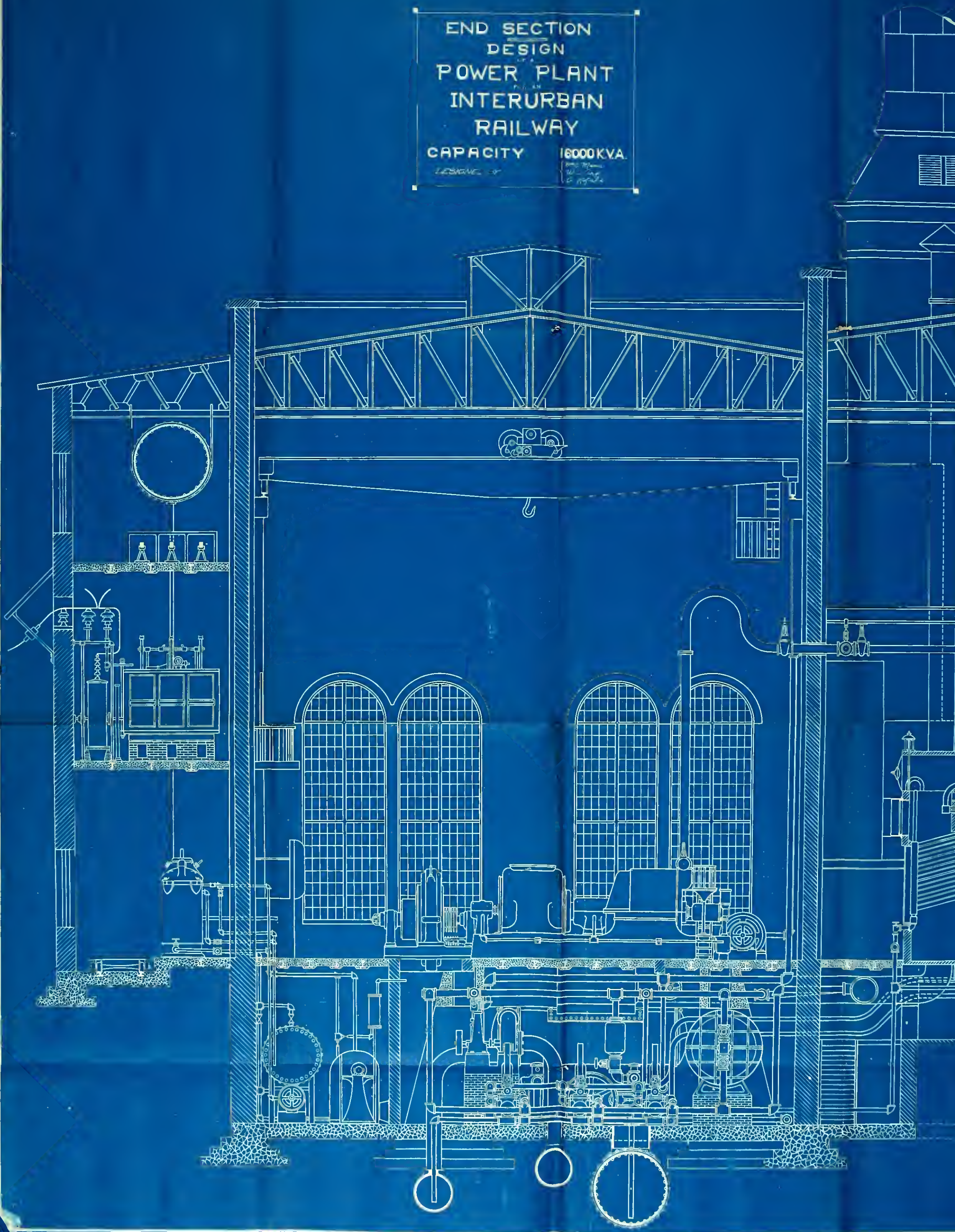
$$= 3x\overline{400}^3 \times 400.298 \times .694/64 \times 15 \times 10^6 \times .1315$$

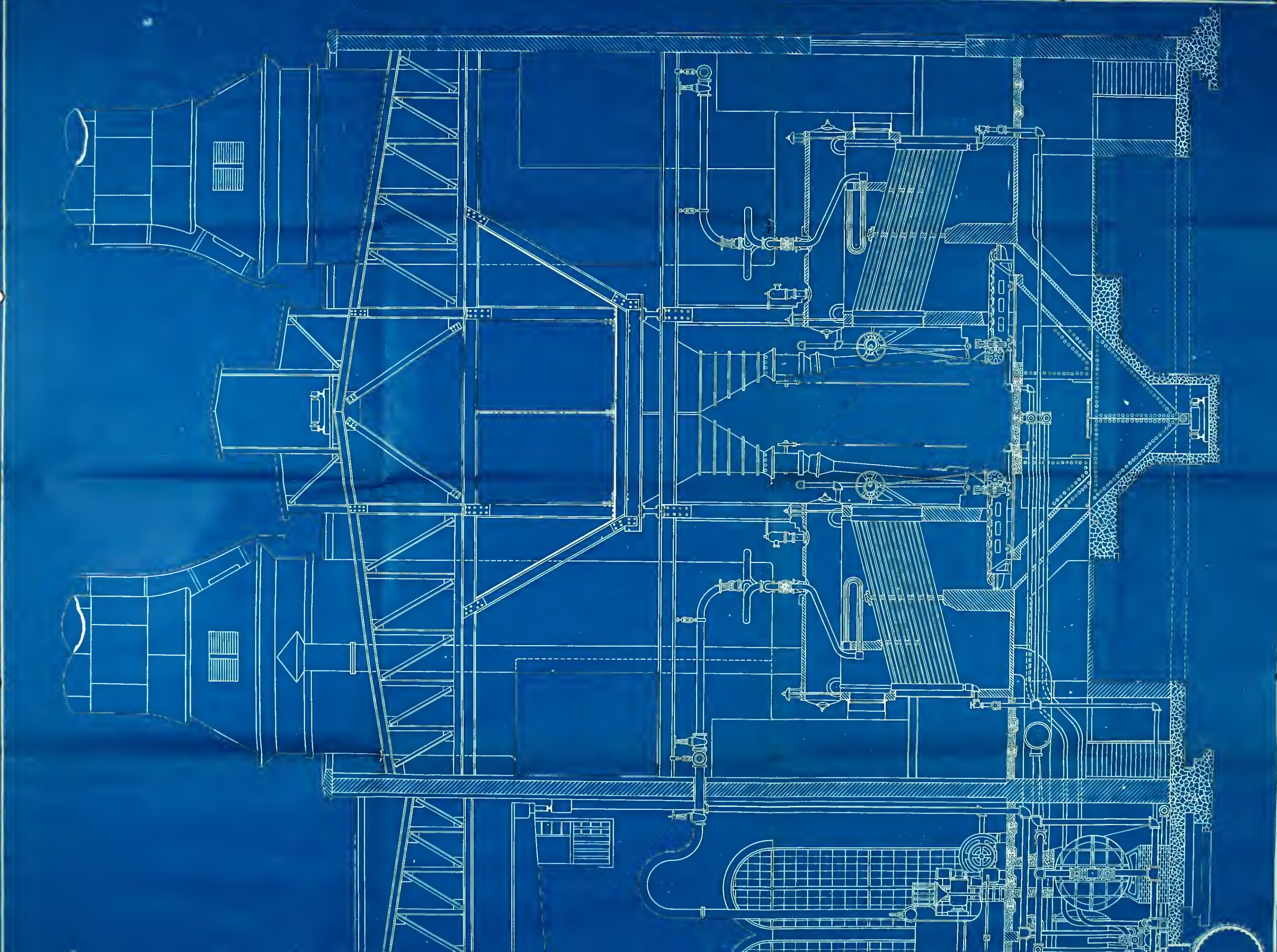
$$D^3 - 145.5D = 425.$$

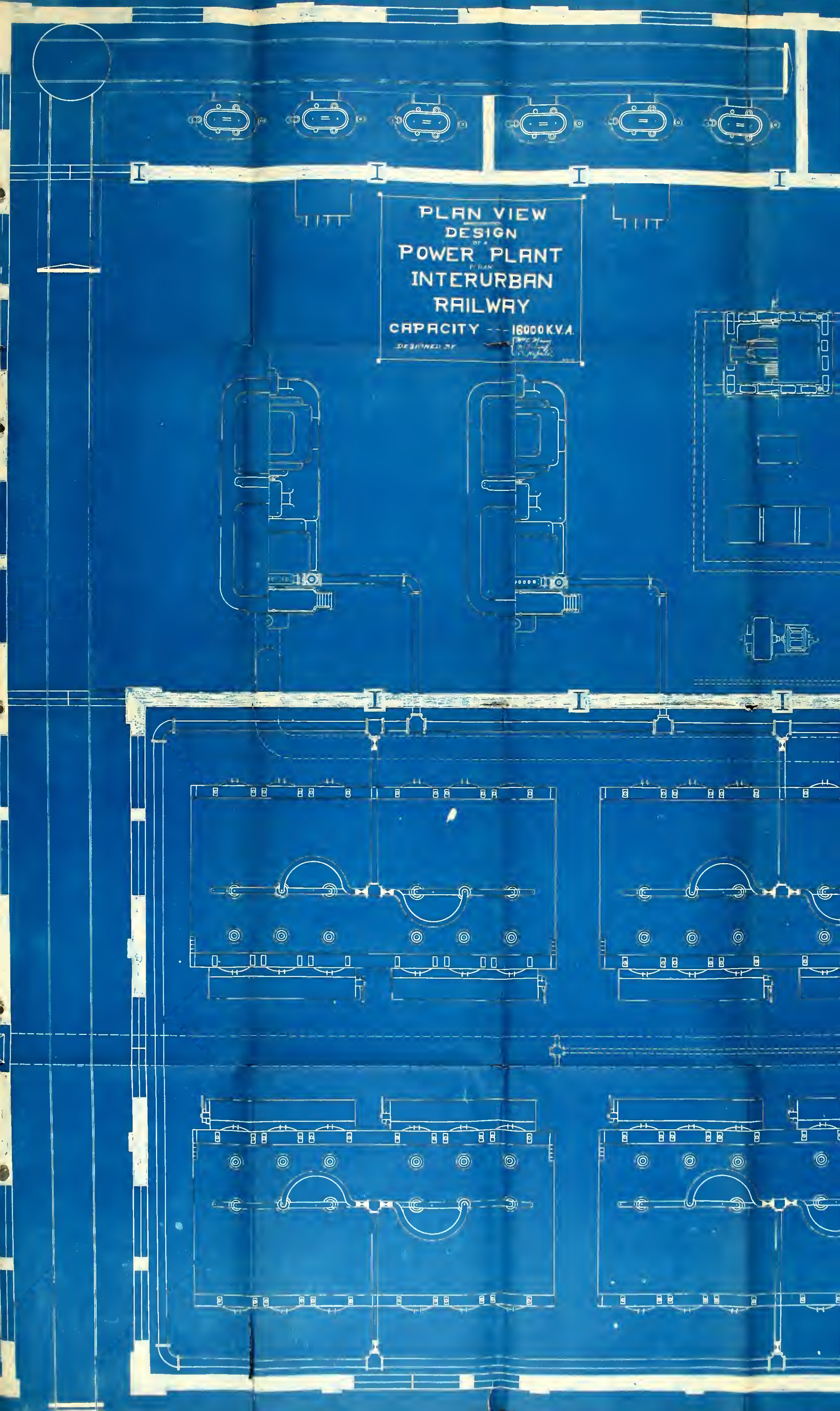
$$D = 13.5 \text{ ft.}$$

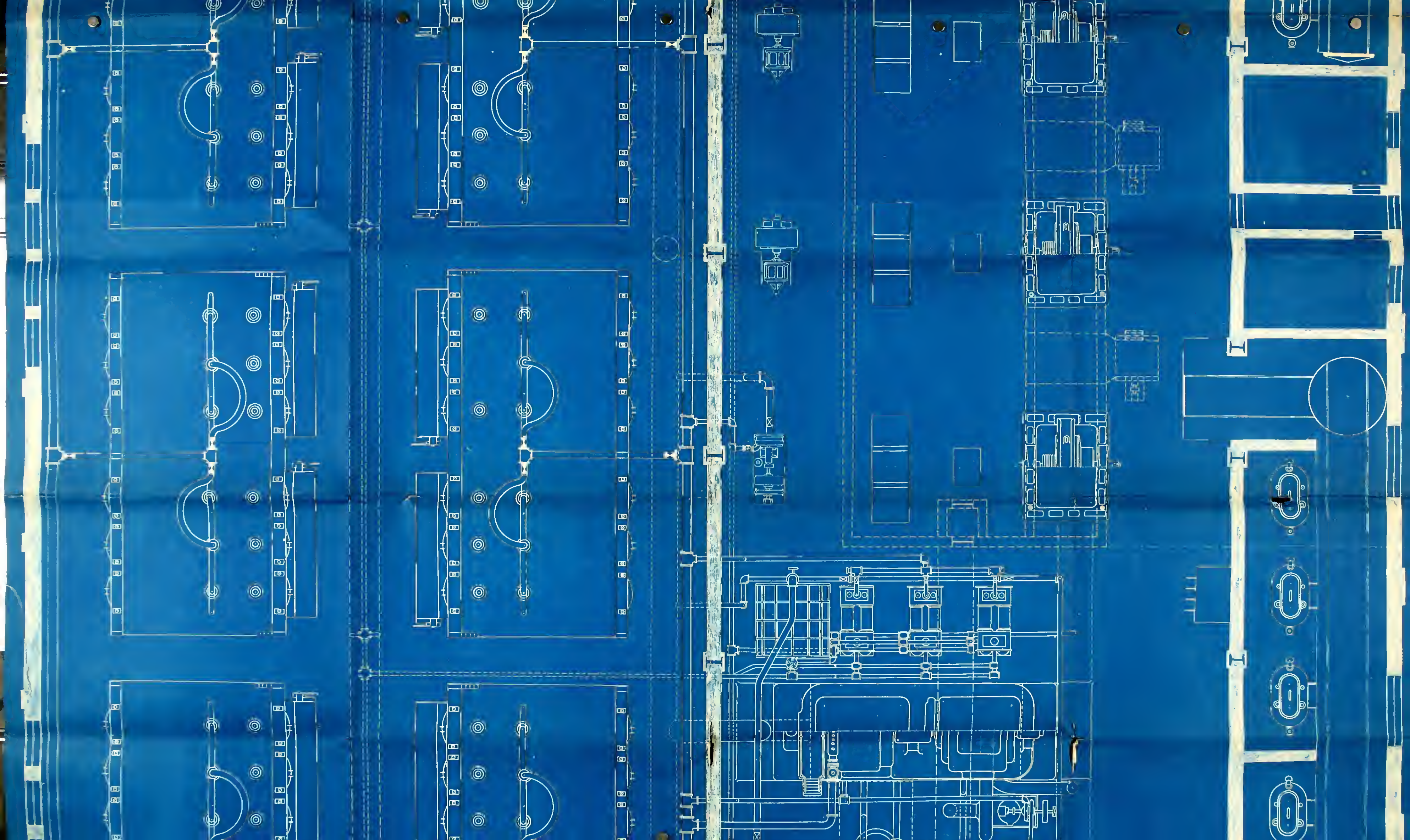
Vertical Sag $= .508/.694 \times 13.5 = 9.85$ ft.

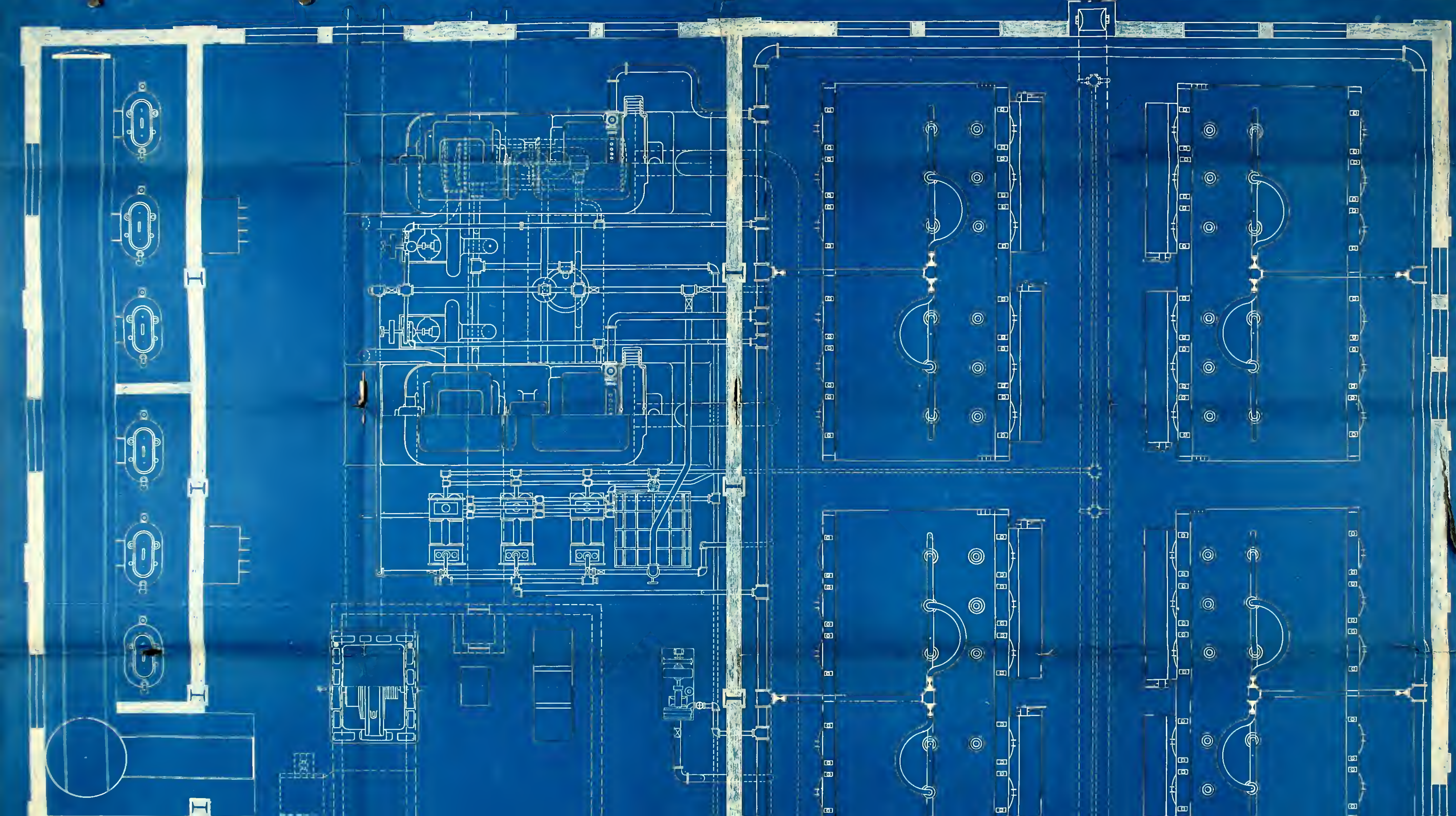
END SECTION
DESIGN
POWER PLANT
INTERURBAN
RAILWAY
CAPACITY 16000 K.V.A.

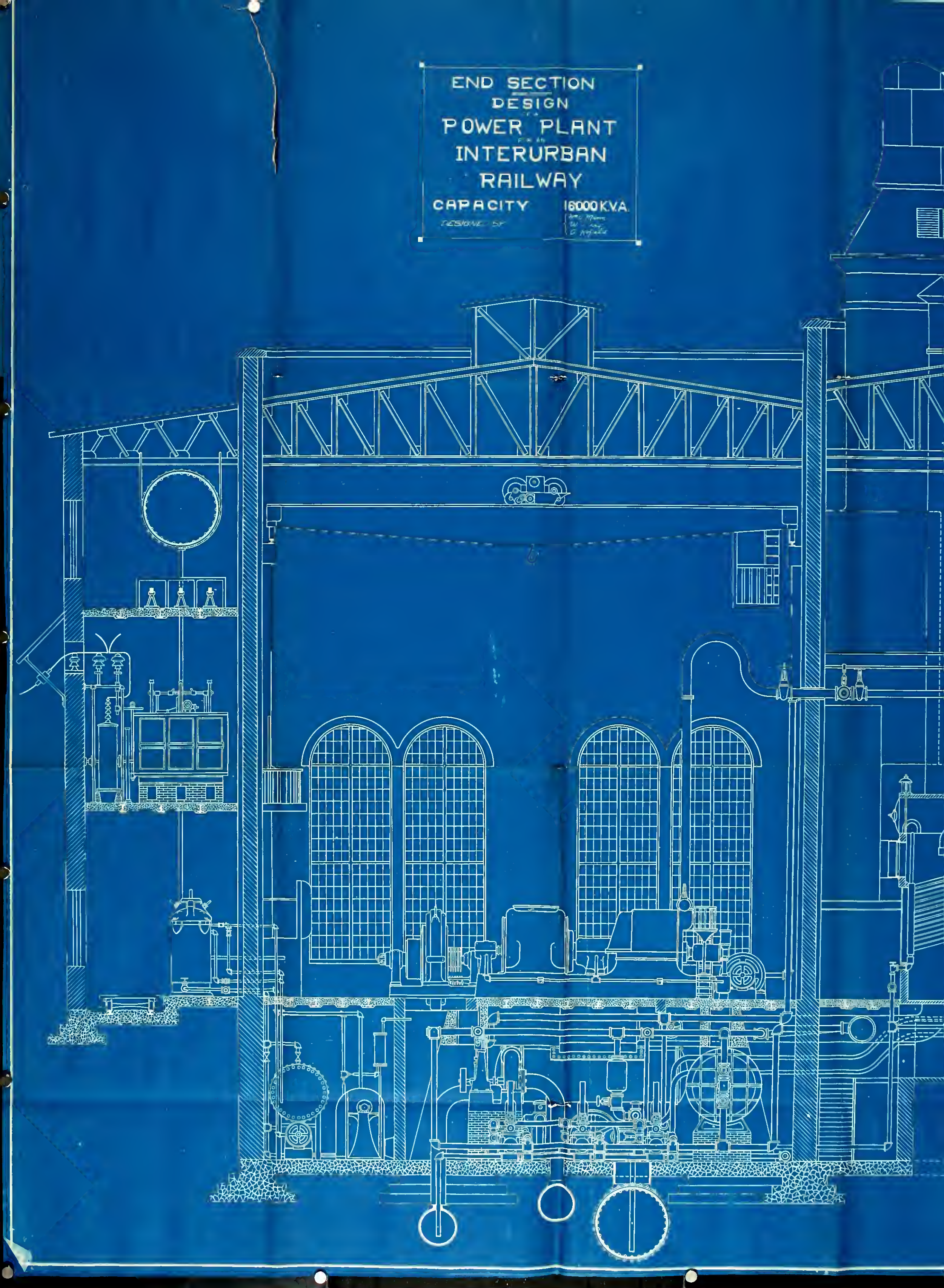





PLAN VIEW
DESIGN
POWER PLANT
INTERURBAN
RAILWAY
CAPACITY --- 16000 K.V.A.
DESIGNED BY



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